GLOBAL DIGITAL TRANSFORMATION

LECTURE 4 – FEATURES

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COURSE

1.	BACKGROUND	What is digital transformation about?
2.	LANDSCAPE	What is the global adoption of digital transformation?
3.	INNOVATIONS	What are the cases of digital transformation?
4.	FEATURES	What features define digital transformation?
5.	BOUNTY	What benefits can digital transformation deliver?
6.	SPREAD	How unequal are the benefits of digital transformation?
7.	WINNERS	Who benefits most from digital transformation?
8.	IMPACT	What is the impact of the bounty and spread?

AIM

The lecture explores three fundamental features of technological progress:

- Exponential – Moor’s law and the second half of the chessboard
- Digital – The digitalization of nearly everything
- Combinatorial – Growing and recombining digital innovations

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

OUTLINE

1.	Exponential	– Moor’s law and the second half of the chessboard
2.	Digital	– The digitalization of nearly everything
3.	Combinatorial	– Growing and recombining digital innovations

WHAT DOES IT MEAN THAT TECHNOLOGICAL PROGRESS HAPPENS EXPONENTIALLY?

GORDON MOORE

Co-founder of Intel, philanthropist, recipient of the Presidential Medal of Freedom.

Cramming More Components onto Integrated Circuits

Electronics Magazine, 1965:

> *The complexity for minimum component costs has increased at a rate of roughly a factor of two per year. . . . Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least ten years.*

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

MOORE'S LAW

Complexity for minimum components costs =
amount of integrated circuit computing power you could buy for one dollar

Back in 1965, this amount doubled every year.

Prediction:

> This will continue for ten more years, i.e. by 1975 electronic circuits will be 2^9=512 times as powerful as those in 1965.

Reality:

> The prediction held true for 40 years!
> The doubling period was revised to 18 months.
> The prediction held for integrated circuits and other areas of digital progress.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

NATURE OF THE MOORE'S LAW

Laws of physics:

Govern thermodynamics or classical mechanics, describe how the universe works, they hold true no matter what we do.

Moore's Law:

A statement about the work of the computer industry's engineers and scientists; an observation about how constant and successful their efforts have been.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

COMPARABLE PROGRESS?

Lack of similar sustained success in other domains:

- Cars are not getting twice as fast or twice as fuel efficient every year for decades.
- Airplanes don't consistently have the ability to fly twice as far.
- Trains cannot carry twice as much.
- Runners don't cut their times in half over a couple of years, even a generation.

How has the computer industry kept up this pace of improvement?

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

REASON 1

While transistors and other computing elements are constrained by the laws of physics just like cars and airplanes, the constraints in the digital world are looser.

- How many electrons per second can be put through a channel in an circuit?
- How fast beams of light can travel through fiber-optic cable?

At some point, digital progress faces its constraints and Moore's Law must slow down, but it takes awhile.

> "Moore's Law is coming to an end—in the next decade it will pretty much come to an end so we have 15 years or so."
>
> Henry Samueli, CTO, Broadcom Corporation, 2013

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

REASON 2

Finding engineering detours around the roadblocks thrown up by physics.

- When it became difficult to cram integrated circuits more tightly, chip makers layered them on top of one another.

- When traffic threatened the capacity of fiber-optic cables, engineers developed wavelength division multiplexing (WDM) to transmit many beams of light of different wavelengths down the same single glass fiber at the same time.

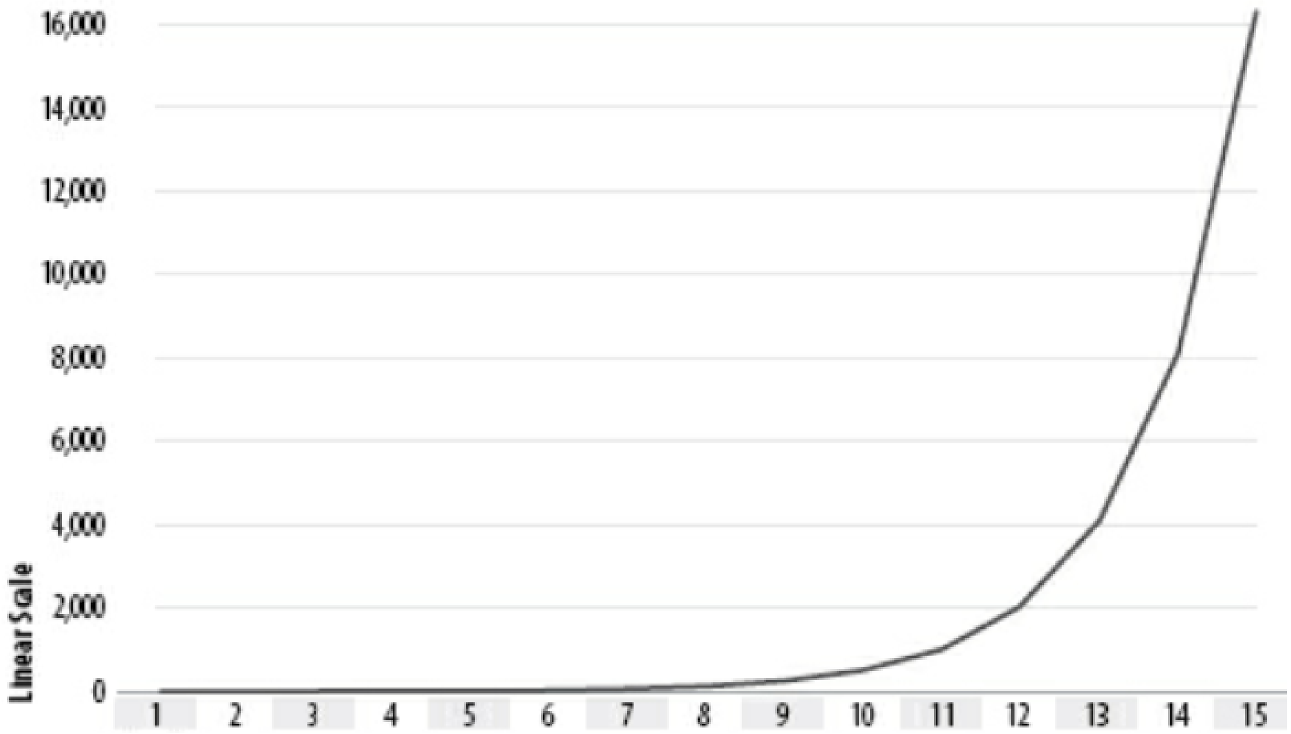
If you're only using the same technology, then in principle you run into limits. The truth is we've been modifying the technology every five or seven years for 40 years, and there's no end in sight for being able to do that.

Mike Marberry, CEO, Intel, 2012

This constant modification has made Moore's Law the central to the computer age.

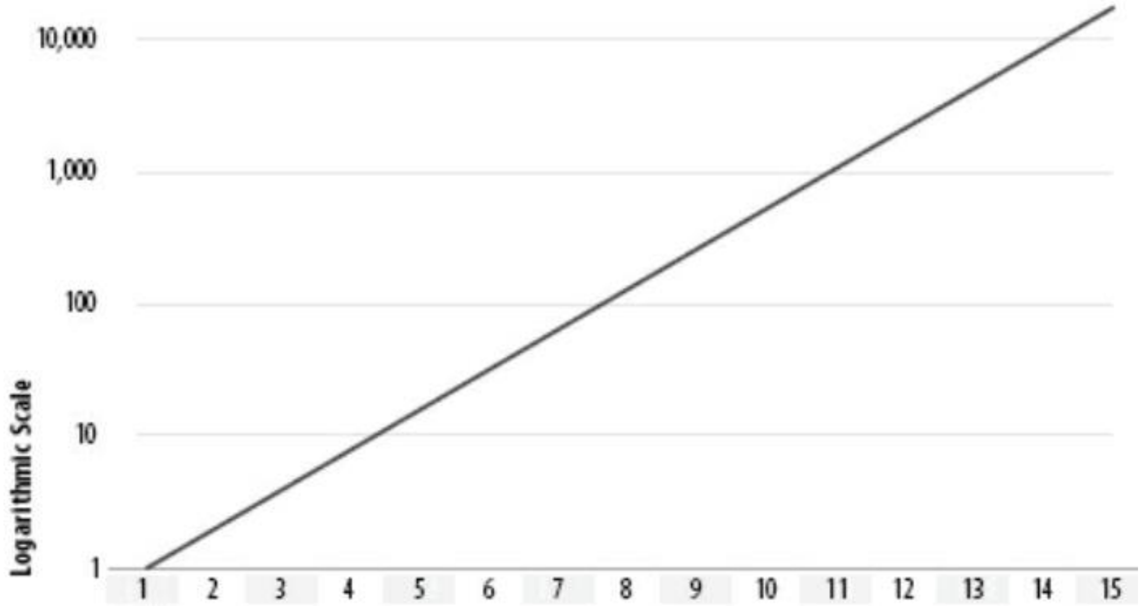
Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

CONSTANT DOUBLING – LINEAR SCALE



Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

CONSTANT DOUBLING – LOGARITHMIC SCALE



Emphasizes the steadiness of the doubling over time rather than the large numbers at the end.

The bigger the exponent, the faster they grow, and the steeper the line.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

GAME OF CHESS AND EXPONENTIAL GROWTH

The game of chess originated in the 6th century in India, at the Gupta Empire.

Storyline:

- The inventor traveled to the capital city to present the game to the emperor.
- Impressed by the game the ruler he invited the inventor to name his reward.
- The inventor said, “All I desire is some rice to feed my family”. He suggested to use the chessboard to determine the amount of rice he would be given:

  Place one single grain of rice on the first square, two on the second, four on the third, etc. so that each square receives twice as many grains as the previous.
- The emperor agreed.

Source: Ray Kurzweil, The Age of Spiritual Machines: When Computers Exceed Human Intelligence, 2000

GAME OF CHESS AND EXPONENTIAL GROWTH

- After 32 squares, the emperor had given the inventor about 4 billion grains of rice, a reasonable quantity but the emperor did start to take notice.

- Heading into the second half of the chessboard would take at last one of them into trouble – the emperor loosing his throne or the inventor loosing his head.

2^{64-1} is more rice than was produced in the history of the world!

Source: Ray Kurzweil, The Age of Spiritual Machines: When Computers Exceed Human Intelligence, 2000

SECOND HALF OF THE CHESSBOARD

While numbers do get large in the first half of the chessboard, we still come across them in the real world. Four billion is within our experience and intuition.

In the second half of the chessboard, however, as numbers mount into trillions, quadrillions, and quintillions, we lose all sense of them and how quickly they grow.

As exponential growth eventually leads to staggeringly big numbers, the second half of the chessboard leaves our intuition and experience behind.

Source: Ray Kurzweil, The Age of Spiritual Machines: When Computers Exceed Human Intelligence, 2000

MOORE'S LAW AND THE SECOND HALF OF THE CHESSBOARD

U.S. Bureau of Economic Analysis which tracks American companies' expenditures, first noted "information technology" as a distinct investment category in 1958.

Take that year as the starting point for the Moore's Law and use eighteen months as the doubling period.

After 32 years of these doublings, U.S. businesses entered the second half of the chessboard concerning digital gear.

That was in 2006.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

SECOND HALF TECHNOLOGIES

Recall technologies described in lecture 2:

1. Self-driving cars
2. Complex communication
3. Language translation
4. Quiz competition
5. Industrial and flexible robotics

All appearing since 2006.

Why progress with digital technologies feels so much faster these days and why we've seen so many recent examples of science fiction becoming business reality?

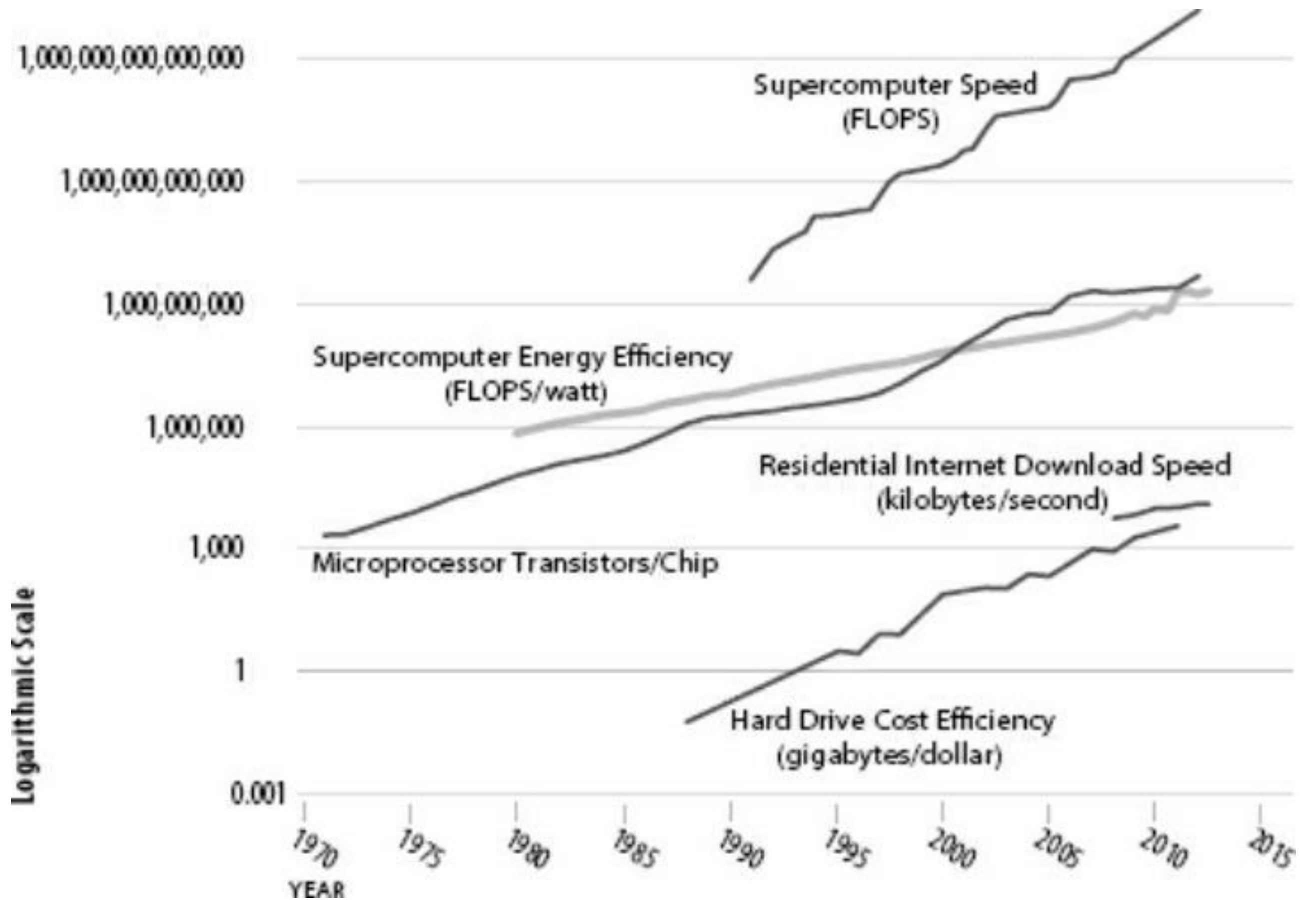
Because the steady exponential growth of Moore's Law has added up to the point that we are in a different regime of computing: in the second half of the chessboard.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DIGITAL PROGRESS ON THE LOGARITHMIC SCALE

Moore's Law is both consistent and broad:

- has been in force for a long time and
- applies to many types of digital progress.



Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: MOORE'S LAW AND THE FUTURE OF TECHNOLOGY

Source: https://www.youtube.com/watch?v=lQyZdrJhOIw

WHAT DOES IT MEAN THAT TECHNOLOGICAL PROGRESS HAPPENS EXPONENTIALLY?

IT MEANS CONTINUED DOUBLING OF VARIOUS PARAMETERS OF DIGITAL PROGRESS OVER TIME.

QUESTIONS

1.	What is the Moore’s law about?
2.	How is the Moore’s law different from the laws of physics?
3.	What are the reasons for the Moore’s law to hold over the last 50 years?
4.	Which areas of digital progress are covered by the Moore’s law?
5.	What the second half of chessboard paradigm tells about digital progress?

OUTLINE

1.	Exponential	– Moor’s law and the second half of the chessboard
2.	Digital	– The digitalization of nearly everything
3.	Combinatorial	– Growing and recombining digital innovations

WHAT DOES IT MEAN THAT TECHNOLOGICAL PROGRESS IS DIGITAL?

WAZE

GPS-based app that provides driving directions.

The software turns all smartphones running it into sensors that upload constantly to the company's servers their location and speed information.

The app knows where our car and other cars are and how fast they were moving, it knows traffic jams, accidents, road closures, and other factors affecting travel time.

Its servers use the static map of roads, the current updates on traffic conditions, and a set of sophisticated algorithms to generate driving directions.

As a result, Waze tells what route to destination is best right at a given moment.

As more and more smartphones run the application, Waze gets a more and more complete sense of how traffic is flowing throughout a given area.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: WAZE VERSUS GOOGLE MAPS

Source: https://www.youtube.com/watch?v=4hT0dPY5q-g

WAZE ENABLERS

1. Exponential technical progress

   Vast numbers of powerful but cheap smartphones, each equipped with an array of processors, sensors, and transmitters.

   Such technology didn't exist two decades ago, Waze only became feasible in the past few years because of accumulated digital power increases and cost declines.

2. Network effects

   The value of digital resource for its users increases with each additional user. The number of Waze users reached 150 mln globally.

   This community had collectively driven billions of miles and typed in thousands of updates about accidents, traffic jams, police speed traps, road closings, etc.

3. Digitization…

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DIGITIZATION

The work of turning all kinds of information and media – text, sounds, photos, video, data from sensors, etc. into binary format.

Waze, for example, uses several streams of information:

1. digitized street maps,
2. location coordinates for cars broadcast by the app,
3. alerts about traffic jams, among others.

It's Waze's ability to bring these streams together and make them useful for its users that causes the service to be popular.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

PROPERTIES OF DIGITAL INFORMATION

- Non-rival

  Rival goods can only be consumed by one person at a time, e.g. one seat on a flight can be only used by one passenger.

  Non-rival goods, particularly digital goods, can be used simultaneously and are not exhausted/used up with every new usage.

- Zero marginal cost of reproduction

  While the very first copy of a digital good might cost a lot to create, making additional copies cost almost nothing.

  In an age of computers and networks, “Information is costly to produce but cheap to reproduce” Shapiro and Varian.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

WHEN THE FIRST COPY IS EXPENSIVE TO MAKE

Instantaneous online translation services example:

- They make use of paired sets of documents that were translated, often at considerable expense, by a human from one language into another.
- Examples: EU issuing all official documents in all languages of its member countries, the UN issuing official documents in six official languages.
- When Google Translate gets a request to translate an English sentence into its German equivalent, it scans all documents it knows in English and German, looks for a close match (or fragments of a close match), and returns the German text.
- Most advanced automatic translation services, do statistical pattern matching over huge pools of digital content that was costly to produce, but cheap to reproduce.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

WHEN INFORMATION IS FREE FROM THE START

Many people are willing to devote their time to producing online content without seeking any money in return:

- Wikipedia's content generated for free by volunteers all around the world.
- Social media sides, websites, blogs, discussion boards, forums, etc. whose users develop content and offer it free of charge to others.
- Six of the ten most popular content sites are primarily user-generated.
- Siri improves itself over time by analyzing the ever-larger collection of sound files its users generate when interacting with the system.
- Machine-to-machine communication…

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

MACHINE-TO-MACHINE COMMUNICATION

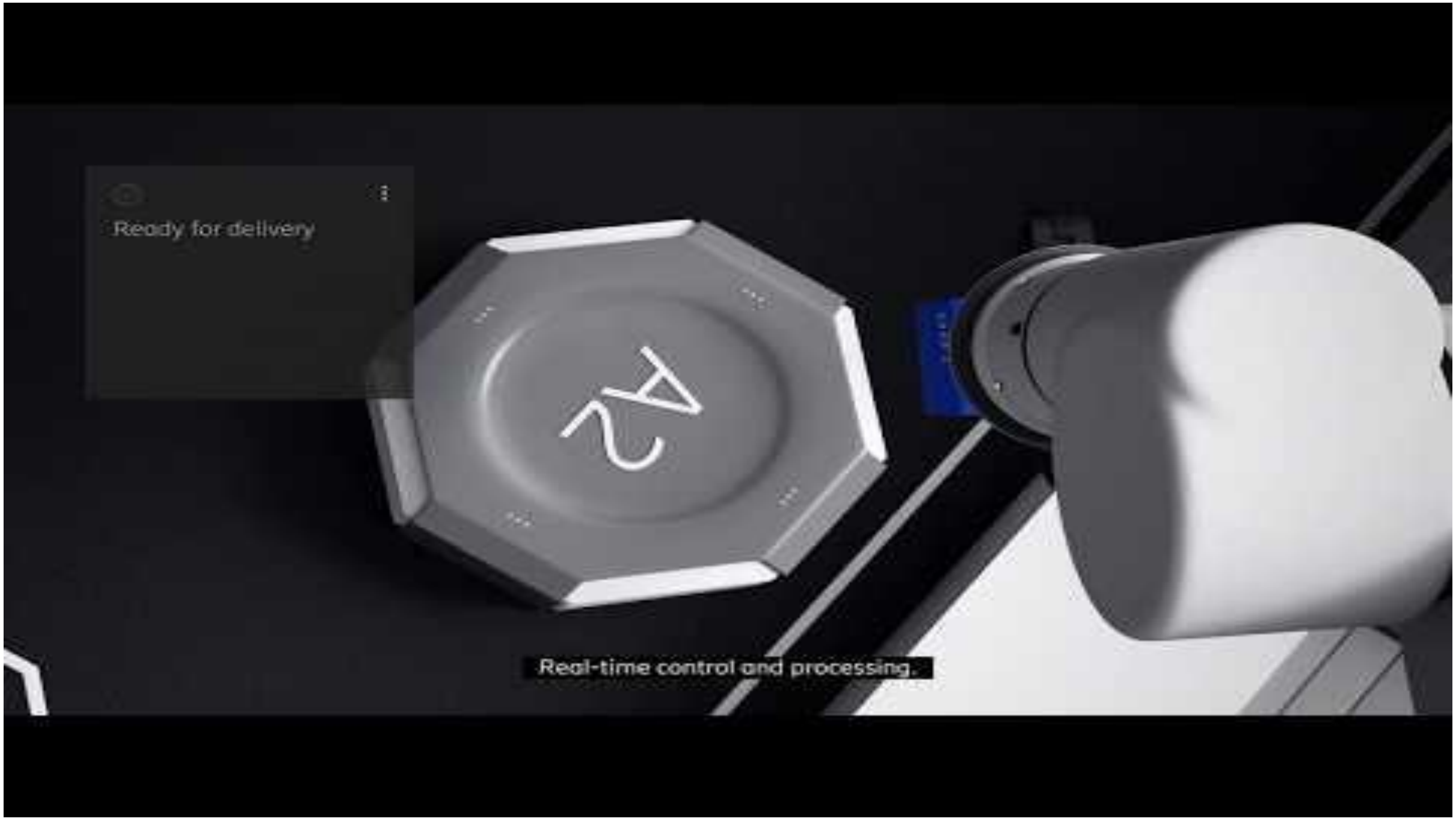
Devices sharing data with one another over the Internet.

- Waze – when active on a smartphone, it constantly sends information to Waze's servers without any human involvement.
- Kayak – when searching for airfares, it sends requests to its counterparts at various airlines, which write back in real time without human involvement.
- ATMs – they ask banks about our accounts balance before letting withdraw cash.
- Digital thermometers in refrigerated trucks – constantly transmit to supermarkets that the produce isn't getting too hot in transit.

"The combined level of robotic chatter on the world's wireless networks . . . is likely soon to exceed that generated by all human voice communications", NYT, 2012

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: CELLULAR INTERNET OF THINGS IS EVOLVING



Source: https://www.youtube.com/watch?v=rhJFDBYmjjw

DATA EXPLOSION

The digitization of everything – documents, news, music, photos, video, maps, social networks, requests and responses, sensor data, etc.

18 zettabytes is the total of all data created, captured or replicated by 2018:

1 zettabyte	= 1000 exabytes
1 exabyte	= 1000 petabytes
1 petabyte	= 1000 terabytes

This data is not just sitting on disk drives, it is moving around.

The world consumed about 833 exabytes (EB) over fixed-broadband connections in 2017, up from 644 EB in 2016, and 502 EB in 2015.

We are soon going to run out of the metric system: 1000 zetabytes = 1 yottabyte.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DATA SCIENCE

Is this explosion of digitization really important? Is digital data useful?

They're incredibly useful. Digitization increases understanding:

- making huge amounts of data readily accessible,
- formulating theories and hypotheses,
- then evaluating such theories/hypotheses based on such data.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DATA SCIENCE EXAMPLES

1. Internet searches versus housing prices and sales:

   Are changes in search-term volume related to later housing prices and sales?

   Yes, if search-terms like

   - "Phoenix real estate agent"
   - "Phoenix neighborhoods"
   - "Phoenix two-bedroom house prices"

   increased today, then housing sales and prices in Phoenix would rise three months from now.

   The model predicted sales 23.6% more accurately than predictions published by the experts at the National Association of Realtors.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DATA SCIENCE EXAMPLES

2. Volume of tweets were as accurate as official reports to tracking the spread of cholera after the 2010 earthquake in Haiti; they were also two weeks faster.

3. Volume of tweets is able to accurately predict movie box-office revenue.

4. Analysis of five million books published in English since 1800 uncovered that the number of English words increased by more than 70% between 1950 and 2000.

“I keep saying that the sexy job in the next ten years will be statisticians. And I’m not kidding.” Hal Varian, 2009

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DATA FOSTERING INNOVATION

Waze and layers of digitization:

1. Digital maps, as old as personal computers.
2. GPS location information, became much more useful for driving when the U.S. government increased its GPS accuracy in 2000.
3. Social data: Waze users help each other by providing information on everything from accidents to police speed traps to cheap gas.
4. Sensor data: converting every car using Waze into a traffic-speed sensor and using these data to calculate the quickest routes.

In-car navigation that uses maps and GPS location have been around for a while.

The founders of Waze realized that adding social and sensor data to an existing system overcomes the shortcomings of traditional GPS navigation.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: DAY IN THE LIFE OF A DATA SCIENTIST

Source: https://www.youtube.com/watch?v=_Wk9T_G-u4o

WHAT DOES IT MEAN THAT TECHNOLOGICAL PROGRESS IS DIGITAL?

IT MEANS THAT THE PROGRESS IS LARGELY DRIVEN BY THE WIDESPREAD DIGITALIZATION OF INFORMATION AND PROCESSES WHICH IN TURN ENABLE DIGITAL INNOVATION

QUESTIONS

1.	What are the pros and cons of Waze compared to Google Maps?
2.	What streams of data are used by Waze? How do they make the app popular?
3.	What are the fundamental properties of digital information?
4.	Why people would create free digital content? Provide examples.
5.	What drives machine-to-machine communication? Provide examples.
6.	Why is digitization and digital data in particular useful?
7.	How is data science utilizing available digital data? Provide examples.

OUTLINE

1.	Exponential	– Moor’s law and the second half of the chessboard
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WHAT DOES IT MEAN THAT TECHNOLOGICAL PROGRESS IS COMBINATORIAL?

GROWTH AND INNOVATION

Most countries don't have mineral wealth and can't get rich by exporting them.

The only viable way for them to improve the standard of living available to its people, is:

- for their workers to keep getting more output from the same number of inputs
- to keep producing more goods/services from the same number of workers

Innovation is how this productivity growth happens.

Innovation is "a series of discrete inventions followed by incremental improvements which ultimately tap the full potential of the initial invention".

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

INNOVATION GETS USED UP

Case of Industrial Revolution:

- There was almost no economic growth for four centuries and probably for the previous millennium prior to 1750

- Once this growth got started, it stayed on a sharp upward trajectory for two hundred years, due to the original Industrial Revolution but also inventions of:

    - electricity,
    - internal combustion engine, and
    - indoor plumbing with running water

  all reliant on technological innovation.

- The technological inventions took full 100 years to have their effect but once the effect was realized, growth stalled and even declined.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

GENERAL PURPOSE TECHNOLOGIES

Powerful technologies are central to economic progress.

To this end, they have to spread throughout many, if not all, industries.

Example – steam engine and electric power spread everywhere, from power and travel to lightening and air-conditioning.

General purpose technologies (GPTs):

> Deep new ideas and techniques that have the potential for important impact on many sectors of the economy, i.e. boost to output due to productivity gains.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DIGITAL TECHNOLOGIES AS GPTS?

GPTs should be pervasive, improving over time, and able to spawn new innovations.

Digital technologies are:

1. Pervasive – are used in every industry in the world;

2. Improving over time – improve along the Moore’s Law; and

3. Able to spawn new innovations – lead to various innovations like self-driving cars, automatic language translation, flexible robotics, etc.

Thus digital technologies are in the same category as electricity or steam power.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

INNOVATIONS DO NOT GET USED UP

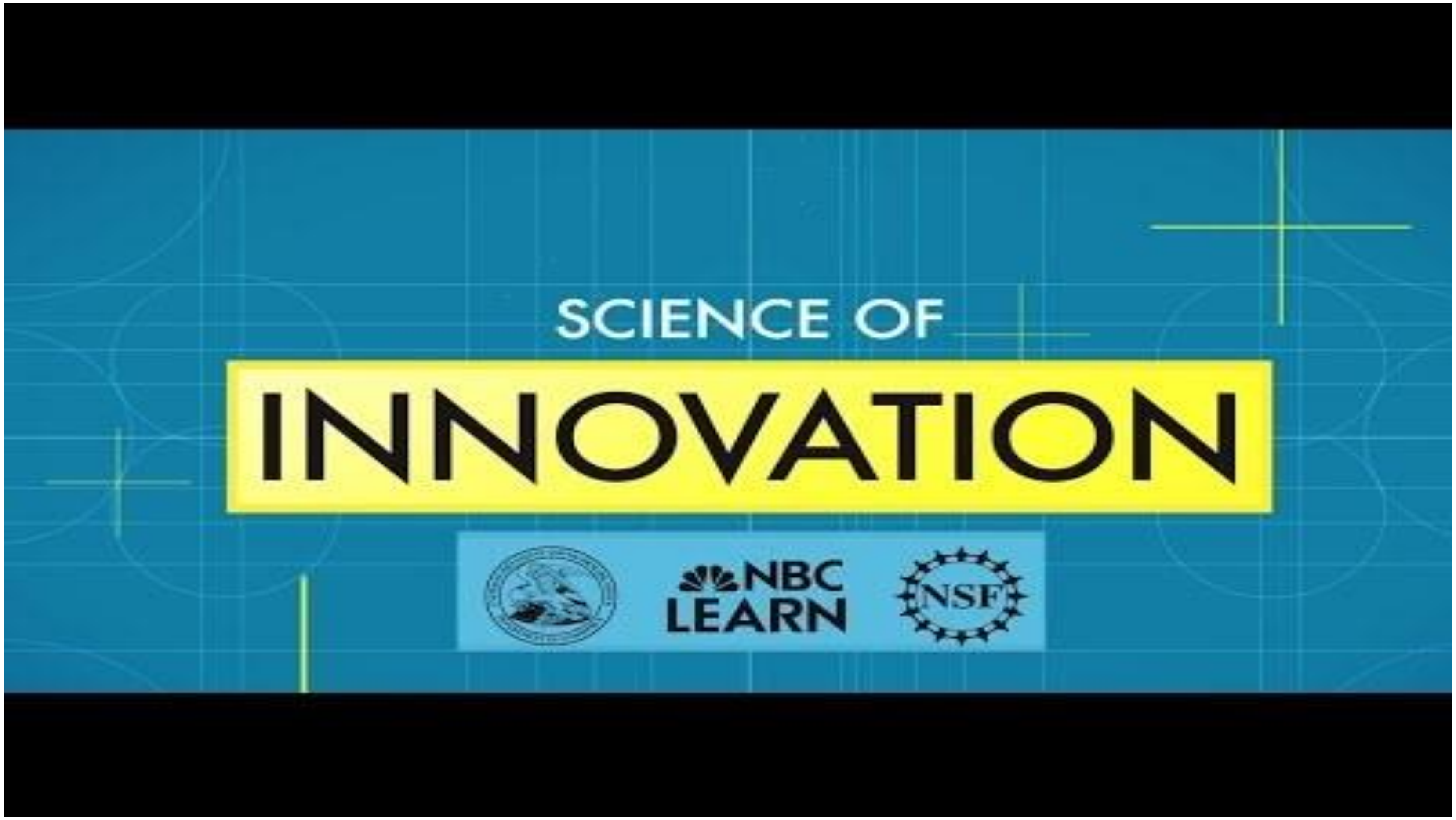
Another view of innovation is not coming up with big and new invention, but instead recombining inventions that already exist.

Economic growth occurs whenever people take resources and rearrange them in ways that make them more valuable.

This recombining of existing inventions are the rule, not an exception.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: WHAT IS INNOVATION? THE SCIENCE OF INNOVATION



Source: https://www.youtube.com/watch?v=UR83B1UuzCY

RECOMBINANT INNOVATIONS, EXAMPLES

1. Auto-piloted cars

   New life to the earlier GPT: the internal combustion engine.

   Equipping everyday car with:

   - Fast computer
   - Large array of sensors
   - Huge amount of street information

2. Car navigation with Waze, which recombines:

   - Location sensor
   - Data transmission device – a phone
   - GPS system
   - Social network

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

RECOMBINANT INNOVATIONS, EXAMPLES

3. World Wide Web, a recombination of:
    - Internet old TCP/IP protocol
    - A markup language HTML
    - Computer software to review HTML pages

   None of the, were particularly novel, their combination was revolutionary.

4. Facebook, building on the WWW infrastructure by allowing people to:
    - Digitize their social network
    - Put media online without having to learn HTML

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

DIGITAL INNOVATION AS RECOMBINANT INNOVATION

Each development becomes a building block for future innovations.

Progress does not run out, it accumulates.

- Progress in the digital world translates to progress in the physical world, e.g. cars that drive themselves, printers that create parts, robots that assemble them, etc.
- Digital gear becomes cheaper, more accessible, and ubiquitous.
- Massive body of data becomes available, relevant in all situations, can be infinitely reproduced and reused as such data is non-rival.

The number of potentially valuable building blocks is exploding and possibilities of recombining them are multiplying.

Innovation as a building block, never used up, always ready to recombine.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

META-IDEAS

The most important of all ideas are meta-ideas – ideas that support the production and distribution of other ideas.

Global digital networks lead to radically new ways of combining and recombining new and old ideas. They constitute the meta-idea.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

LIMITS TO RECOMBINANT GROWTH

As combinatorial possibilities explode quickly, there is soon a virtual infinite number of potentially valuable recombinations of existing knowledge pieces.

The main constraint on economic growth is the ability to go through all potential recombinations to find the truly valuable ones.

In the early stage of development, growth is constrained by the number of potential new ideas, but later on it is constrained only by our ability to process them.

Source: E. Brynjolfsson and A. McAfee, The Second Machine Age, 2016

VIDEO: COMPONENTS OF THE SECOND MACHINE AGE

Source: https://www.youtube.com/watch?v=Nrsh7GSj9lk

WHAT DOES IT MEAN THAT
TECHNOLOGICAL PROGRESS IS COMBINATORIAL?

IT MEANS THAT DIGITAL INNOVATIONS
BUILD UPON EACH OTHER, AND AS THEY RECOMBINE,
THEY GIVE RISE TO NEW DIGITAL INNOVATIONS

QUESTIONS

1.	What makes productivity and economic growth improve?
2.	Is it possible for innovation to get used up?
3.	What is General Purpose Technology (GPT)?
4.	Is digital technology an instance of GPT? Why?
5.	Why is innovation never getting used up?
6.	Provide examples of recombinant digital innovations.
7.	What are the limits to recombinant growth?

THANK YOU FOR YOUR ATTENTION

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